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CONTENTS OF VOLUME 19

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REDETERMINATION OF SECONDARY STANDARDS OF WAVE LENGTH FROM THE NEW INTERNATIONAL IRON ARC

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REDETERMINATION OF SECONDARY STANDARDS OF WAVE LENGTH FROM THE NEW INTERNATIONAL IRON ARC.

By W. F. Meggers, C. C. Kiess, and Keivin Burns.

ABSTRACT.

The system of secondary standards of wave length now in common use was derived from an axial part about 2 mm wide in the center of an iron arc about 6 mm long, and was established before the full importance of operating conditions of sources was recognized. In this type of arc certain lines, grouped as c and d lines because of their sensitiveness to pressure, appeared to be displaced with respect to others grouped as a and b lines, so that the International Astronomical Union in 1922 recommended that the length of the arc be 12 to 15 mm and that light be taken from a central zone not to exceed 1–1.5 mm in width. These changes in the standard iron arc made it desirable to redetermine the secondary standards of wave length. The well-known interferometer method of Fabry and Perot was employed to measure wave lengths of selected lines in the iron spectrum directly in terms of the primary standard, the wave length of the red radiation from cadmium which served for the wave-length meter comparisons. New results are given for 159 lines between 3370 A and 6678 A, including 84 of the international secondary standards. For 23 lines belonging to groups c and d, the secondary standards minus the new values averages +0.0072 A. There is also a systematic difference for lines of groups a and b, 44 such lines averaging 0.0029 A less than the present international values. The reason for the latter divergence is not obvious, but it may be due to a real error in the international system, which, it is pointed out, was not established strictly according to the logical definitions of such a system nor with the accuracy which might be possible now in a redetermination.

CONTENTS.

I. INTRODUCTION.

An international system of secondary standards of wave length, derived from the iron arc spectrum, was established by the International Union for Cooperation in Solar Research during the years 1905 to 1913. This system comprises 86 values [1] extending from 3370.789 A in the ultra-violet to 6750.163 A in the red, and for more than a decade it has been used very extensively in spectroscopy and astrophysics. The values are based upon three independent observations by the interferometer method of Fabry and Perot, and are referred to the value 6438.4696 A, obtained by

[1] J. O. S. A., 5, p. 308; 1921.

Benoit, Fabry, and Perot, for the red radiation of cadmium in terms of the meter. The actual comparisons of wave length were made before the full importance of operating conditions of sources was realized and it was not until 1913 that the iron arc in air as a source of international standards [2] was carefully specified as follows: Length of arc 6 mm; current of 6 amperes for wave length greater than 4000 A, 4 amperes or less for wave lengths shorter than 4000 A; direct current with positive pole above the negative, potential of 220 volts; iron rods of 7 mm diameter for electrodes; axial part about 2 mm wide in center of arc to be used as the source of light; only lines of groups a, b, c, d to be used as standards. Somewhat later, it was shown by investigations [3] at the Mt. Wilson Observatory that the lines of groups c and d were displaced toward the red in this type of arc. This displacement, affecting about 20 of the secondary standards, was regarded as a change in wave length of these lines as compared with lines of groups a and b, which were assumed to be independent of ordinary variations in the source.

In July, 1919, the International Astronomical Union was organized to replace the union which existed before the war and its transactions for 1922 contained the following statement with respect to the iron arc: [4]

> In order to obtain lines of constant wave length, constant intensity distribution and adapted to high orders of interference, the adoption is recommended of the Pfund arc operated between 110 and 250 volts, with 5 amperes or less, at a length of 12–15 mm used over a central zone not to exceed 1–1.5 mm in width, and with an iron rod 6–7 mm diameter as the upper pole and a bead of oxide of iron as the lower pole.

In view of these radical changes in the standard iron arc, it became desirable to redetermine the secondary standards of wave length, and in this paper new results are given for 159 lines, including 84 of the international secondary standards.

II. APPARATUS AND METHODS.

A newly constructed iron arc was used in this investigation. The arc stand without electrodes is shown in Figure 1. In order to select the proper length and portion of the arc, it is convenient to have adjustments in three dimensions as well as additional ones for aligning and separating the electrodes. Iron rods 7 mm in diameter were used as electrodes and the upper or positive pole was surrounded by a close fitting brass cylinder perforated with holes to serve as a radiator.

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[2] Trans. I. U. S. R., **4**, p. 58; 1914.

[3] Astroph. J., **42**, p. 231; 1915; Ibid., **46**, p. 138; 1917.

[4] Trans. I. A. U., **1**, p. 36; 1922.

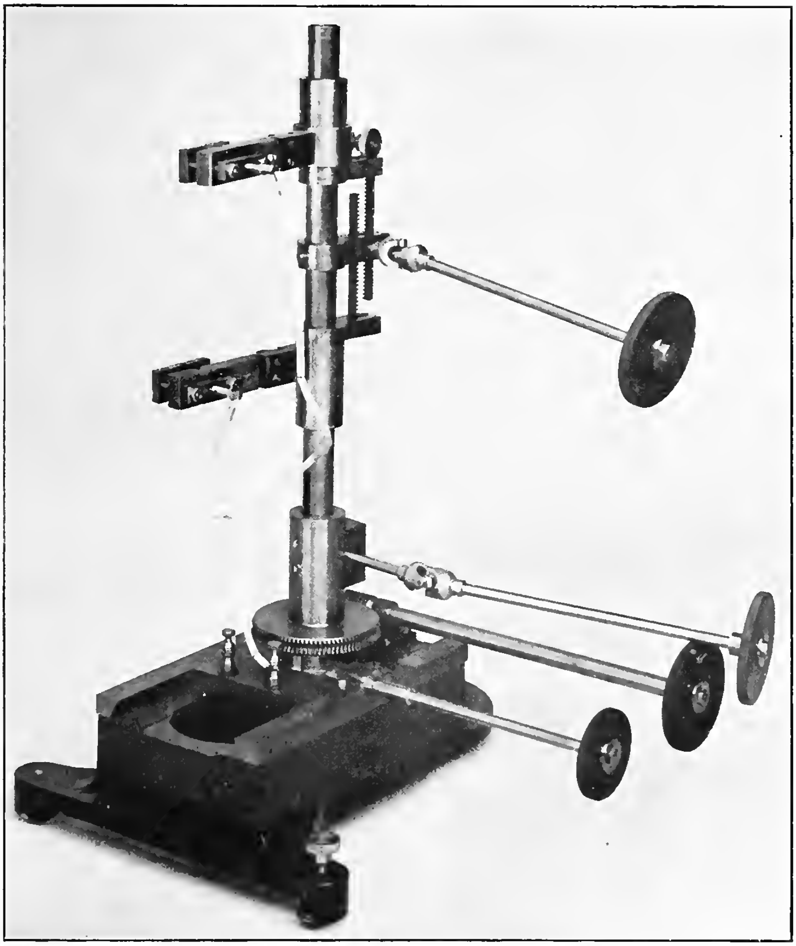

FIG. 1.—*New stand for the iron arc.*

The cadmium source was a spectrum tube of the H type similar to the one described by Michelson. This type of tube served as a source in both of the meter measurements in terms of the wave length of the red radiation from cadmium vapor, and is the one mentioned in the definition of the unit of wave length.[5] The International Astronomical Union has defined some auxiliary standards[6] in the neon spectrum as equivalent in most cases to the primary standard, and we have accordingly used neon tubes for part of the comparison exposures. Tubes similar to the one used for neon and cadmium wave-length comparisons [7] were employed and served in every case to determine the order of interference in the convenient manner described heretofore.[7]

A quartz lens projected a fourfold magnified image of the arc on the interferometer which was diaphragmed to a 6 mm aperture, the latter thus receiving light from about 1.5 mm in the center of a 12 mm arc.

Nearly half of the exposures were made simultaneously to the iron arc and the comparison sources, cadmium or neon, and in such cases the light from the arc was reflected to the interferometer by a thinly silvered mirror, through which the light from the comparison sources passed. When exposures were not made simultaneously the comparison source was photographed both before and after the iron arc, and the iron wave lengths were then derived from the mean of the two comparison exposures. An arrangement whereby exposures could be made simultaneously to three different sources, viz, iron, cadmium, and neon, was also tried, but finally discarded because of its wastefulness of light.

Two sets of interferometer plates were employed, the one set being cathodically covered with semitransparent films of silver and the other with nickel. Various separations of the interferometer plates were used in different exposures, the separators or étalons being of invar and having lengths ranging from 3 to 15 mm. The interferometer plates were mounted in the cylindrical holder described elsewhere [8] and the whole interferometer was slipped into a long brass tube packed in granulated cork, and thus protected from any air currents and outside temperature changes which might occur.

For dispersing the spectra the stigmatic concave grating mounting described before [9] was employed. The observations were made

[5] Trans. I. U. S. R., 2, p. 20; 1908.
[6] Trans. I. A. U., 1, p. 35; 1922.
[7] B. S. Sci. Papers, 12, p. 203; 1915.
[8] B. S. Bull., 14, p. 711; 1918.
[9] B. S. Sci. Papers, 18, p. 191; 1922.

in a basement laboratory whose diurnal temperature fluctuations are negligible, and both the arc and the cadmium lamp furnace were inclosed in ventilated hoods so that there was no difficulty with temperature effects on the apparatus.

Schleussner "ultra-rapid" plates, 40 cm long by 6 cm wide, were employed in photographing the spectra. These plates were of extra thin glass, which permitted them to be bent to the best focus for spectral lines and interference rings throughout the entire spectrum extending from about 3000 A in the ultra-violet to about 7000 A in the red. The end of the plate used for recording the yellow, orange, and red was sensitized by bathing in a pinacyanol solution. The light from the iron arc was passed through a Wratten minus blue filter for part of the long exposures in order that the green, yellow, and red portions of the spectrum might be more comparable with the ultra-violet in photographic density. Some extra short exposures were made in order to obtain good images of the stronger lines which were otherwise generally over-exposed, especially in the ultra-violet. A summary of the plates and data relating to them is contained in Table 1.

TABLE 1.—Summary of Observations.

Plate No.	Étalon.	Film.	Exposures of sources (in minutes).
	mm		
G 1381	3	Ni	Ne, 25; Fe, 40; Ne, 20.
G 1383	5	Ni	Cd, 25; Fe, 45; Ne, 12.
G 1384	7.5	Ni	Cd, 20; Fe, 60; Ne, 12.
G 1385	10	Ni	Cd, 30; Fe, 60; Ne, 12.
G 1398	3	Ag	Cd, 50; Fe, 60; Fe, 5; Ne, 15.
G 1399	5	Ag	Cd, 35; Fe, 60; Fe, 3; Ne, 10.
G 1400	7.5	Ag	Cd, 30; Fe, 70; Fe, 3; Ne, 10.
G 1401	7.5	Ag	Cd, 20; Fe, 90; Fe, 5; Ne, 12.
G 1402	10	Ag	Cd, 20; Fe, 90; Fe, 1.5; Ne, 10.
G 1403	15	Ag	Cd, 25; Fe, 90; Fe, 1.5; Ne, 12.
G 1404	5	Ag	Ne, 10; Fe, 80; Fe, 1.5; Ne, 10.
G 1405	3	Ag	Ne, 15; Fe, 70; Fe, 1.5; Ne, 20.
G 1417	10	Ag	Fe, Ne, simultaneously, 40.
G 1418	10	Ag	Fe, Ne, simultaneously, 60.
G 1419	10	Ag	Fe, Ne, simultaneously, 5, 60.
G 1420	7.5	Ag	Fe, Ne, simultaneously, 1, 60.
G 1439	7.5	Ag	Fe, Ne, simultaneously, 65.
G 1440	7.5	Ag	Fe, Ne, simultaneously, 60.
G 1441	7.5	Ag	Fe, Cd, simultaneously, 60.
G 1442	7.5	Ag	Fe, Ne, simultaneously, 75.
G 1444	5	Ag	Fe, Cd, simultaneously, 75.
G 1446	3	Ag	Fe, Cd, simultaneously, 60.

Thege neral theory of the classical étalon interferometer method of Fabry and Perot[10] for wave-length comparisons is so well known, both as to the arrangement of apparatus and reduction of the results, that it does not require repetition here. Details

[10] Ann. de Chim. et. de Phys., 25, p. 110; 1902.

about the particular apparatus and procedure involved in the present investigation have already been given above and the following remarks on measurements, computations, and corrections should suffice. In general, the diameters of two interference rings were measured for each standard line, the innermost ring either being avoided if its fractional order was less than 0.4 or being supplemented by observations on the third ring. Several of the plates were reduced from measurements of three rings for each line. The computations were made by means of the formula

$$\lambda_1 = \frac{\lambda P}{P_1}\left(1 + \frac{d^2}{8R^2} - \frac{d_1^2}{8R^2}\right)$$

in which λ_1 represents the wave length of a secondary standard to be ascertained in terms of λ, the wave length of the primary standard, P_1 and P are, respectively, the orders of interference producing the first ring in each case, d_1 and d represent the linear diameters of these two rings, respectively, and R is the focal length of the lens which focuses the interference rings on the slit of the spectrograph. Small corrections required by deviation of the observing conditions from the standard temperature and atmospheric pressure were made according to the Bureau of Standards tables,[11] which have been adopted for this purpose by the International Astronomical Union. The corrections for the so-called dispersion of phase change were determined from étalons of various sizes [12] and were confirmed by a supplementary set of observations on neon and mercury lines for which étalons up to 25 mm in length were used.

III. RESULTS.

The original recommendation in establishing an international system of standard wave lengths was that secondary standards be determined by an interference method at intervals of 50 Angstroms, and that tertiary standards be derived from these by interpolation. Since the labor involved in measuring wave lengths directly in terms of the primary standard is not much greater than that required for the same precision by interpolation, we have in the present work measured lines at closer intervals. In Table 2 we present results for 159 lines, including 84 of the international secondary standards, in the spectral range 3370 to 6678 A, thus

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[11] B. S. Bull., **14**, p. 728; 1918. [12] B. S. Bull., **12**, p. 199; 1915.

giving standards at intervals which average about 20 A. Column 1 in Table 1 describes each line as to intensity, group, and class, the relative intensities being the estimates of Burns,[13] while the data on group and class, as far as these are available, are taken from Gale and Adams,[14] and additional group classifications by St. John and Babcock.[1]

The wave lengths resulting from direct comparison with the primary standard are found in column 2, followed by the number of observations and the probable error for each value. "A" indicates a probable error less than 0.0007 A, "B" corresponds to a probable error between 0.0007 A and 0.0012 A, while "C" means that the determination is poor. For comparison with column 2, column 5 contains the fractional values of the international secondary standards and column 6 the interpolated values and tertiary standards adopted by the International Astronomical Union.[16]

With respect to the choice of standards, the International Astronomical Union has expressed itself as follows: [17]

> It is very desirable to eliminate as far as possible the unstable standards belonging to groups c 5 and d. The list of proposed tertiaries shows that stable Fe lines are available as soon as their wave lengths are referred directly to the red cadmium line, except for the short gap between 4700 and 4800 A and for the region 5500–6000 A. This long gap can be partially filled by neon lines, whose wave lengths have been referred to the red cadmium line by three observers, and this entire gap as well as that at 4750 A can be filled with good solar lines, when their wave lengths in integrated sunlight have been determined by a sufficient number of interferometer observations.

It should be emphasized, however, that no solar spectrum standards on the new international scale are, as yet, available, and that not all laboratories have access to the solar spectrum. Furthermore, it is conceivable that in some cases the use of a neon tube requiring different electrical facilities than the iron arc, may be inconvenient. Since the neon lines fill only one-third of one of the gaps mentioned above, it is perhaps doubtful if the neon tube will be very generally employed to supplement the iron arc. For these reasons we believe that it is highly desirable to make the iron arc serve, as far as possible, as a source of standards for the entire range of wave lengths, and we have, therefore, in our measurements, included 17 lines of group c, 22 of group d, and 3 of group e to fill the spectral regions, either because no other iron lines are available there or to distribute the standards more evenly. Ac-

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[13] Lick Observatory Bulletin No. 247, also Zeit. f. Wiss. Phot., **12**, p. 209; 1912.
[14] Astroph. Jour., **35**, p. 10; 1912; also, Astroph. Jour., **37**, p. 391; 1913.
[15] Astroph. Jour., **53**, p. 260; 1921.
[16] Trans. I. A. U., **1**, p. 41; 1922.
[17] Ibid., p. 38.

cording to our experience any and all of these values are strictly reproducible under the same observing conditions and may be used with confidence in precision measurements of lengths.

TABLE 2.—Standard Wave Lengths in the Iron Arc Spectrum.

Intensity, group and class.	λ B. S.	Number of observations.	Probable error.	Secondary standards.	Interpolated.	Intensity, group and class.	λ B. S.	Number of observations.	Probable error.	Secondary standards.	Interpolated.
6	3370.786	9	A	789	788	5 c 4	4494.568	25	A	572	571
6	3399.337	13	A	337	337	2	4517.529	4	B	......	532
6	3428.196	11	A	......	......	7 c 4	28.619	15	A	......	622
4	3445.151	18	A	154	153	5 b 3	31.152	24	A	155	155
6	3485.343	11	A	345	343	3 b	47.851	16	A	853	854
5	3513.821	11	A	821	821	2	74.725	3	C	......	......
4	27.796	6	B	......	......	4	4592.655	21	A	658	657
6	56.882	13	A	881	881	4	4602.945	26	A	947	946
5	58.517	3	C	......	519	4 d	25.054	14	A	......	......
4	3575.374	10	A	......	......	4 b	47.437	22	A	439	439
5	3606.683	24	A	682	682	5 c 4	78.853	17	A	......	856
5	23.188	20	A	......	188	4 c 4	4691.414	18	A	417	417
6	40.393	28	A	392	392	5 c 5	4707.282	19	A	288	290
4	76.315	20	A	313	313	3 b	10.287	17	A	......	288
6	77.631	20	A	629	629	3 a	33.596	12	A	......	598
3	3695.055	18	A	......	054	5 c 5	36.782	24	A	786	790
5	3704.464	3	C	......	464	3 b	41.533	8	A	......	535
6	24.381	30	A	380	380	3 b	72.818	8	B	......	818
5	53.615	31	A	615	615	3 b	4789.654	18	A	657	656
5	3785.955	9	B	......	950	5 c 5	4859.748	23	A	758	759
6	3805.346	24	A	346	346	5 c 5	4878.219	22	A	225	224
5	43.261	22	A	261	260	5 c 5	4903.317	21	A	325	326
6	65.526	8	B	527	527	8 c 5	19.001	25	A	007	008
4	73.764	16	A	......	764	3 a	24.775	11	A	......	776
4 b	3891.932	8	A	......	......	3 a	39.692	13	A	......	691
5 a 1	3906.483	10	B	482	483	5 c 5	66.097	15	A	104	106
3 b	07.938	18	A	937	937	3 a	4994.132	17	A	......	135
4 b	35.816	22	A	818	817	5 c	5001.872	21	A	881	881
4 b	49.958	21	A	......	......	4 a	12.072	23	A	073	073
5 b 4	77.744	24	A	746	746	4 a	41.758	19	A	......	760
6 b 4	3997.397	3	C	......	397	5 a	49.825	20	A	827	827
5 a	4009.716	20	A	......	718	4 c	68.774	12	A	......	......
5 b	21.870	24	A	872	872	4 a	5083.343	18	A	344	343
3	74.789	21	A	......	792	4 a	5110.414	19	A	415	415
5 b	76.636	12	A	642	638	4 a	23.722	16	A	......	725
3 b	4095.974	19	A	......	977	3 a	27.362	14	A	......	365
5 b	4107.492	26	A	......	495	4 a	50.843	15	A	......	845
6 b	18.549	23	A	552	552	8 a	67.490	24	A	492	493
5 b 4	34.680	21	A	685	684	7 c	91.462	20	A	......	......
4 b	47.673	24	A	676	675	8 d	92.353	22	A	363	360
4 b	56.802	25	A	......	805	4 a	5198.715	15	A	......	715
4 b	75.639	19	A	......	642	5 a	5202.339	19	A	......	340
4 b	84.894	26	A	......	897	5 a	16.277	22	A	......	280
6 d	4191.436	20	A	443	444	8 d 5	32.948	23	A	957	956
3 b 3	4203.986	23	A	......	988	3 a	42.496	9	B	......	496
5 b	19.364	23	A	......	367	3	50.650	12	A	......	652
6 d 5	33.609	20	A	615	614	8 d 5	66.564	26	A	569	571
2 b	45.260	19	A	......	261	8 a 4	70.361	11	A	......	360
2 b	67.831	13	A	......	832	7 d	5283.629	20	A	......	......
6 b 1	82.406	23	A	408	408	5 d	5302.308	18	A	315	315
2	4298.040	3	A	......	043	2 a	07.364	12	A	......	365
5 b 3	4315.087	20	A	089	090	6 d 5	24.187	23	A	196	196
5 b 3	37.049	21	A	......	052	4 a 4	28.532	9	C	......	537
4 b 3	52.738	23	A	741	740	5 a 4	41.026	24	A	......	028
5 a 3	75.932	22	A	934	934	7 a 1	71.493	26	A	495	495
3 b	4390.954	14	A	......	956	6 a 4	5397.131	19	A	......	134
4 c 4	4408.419	16	A	......	421	6 a 4	5405.778	26	A	780	780
5 a 3	27.312	24	A	314	314	6 a 4	34.527	28	A	527	528
5 c 4	47.722	20	A	......	724	6 a 4	55.613	22	A	614	615
5 b 4	66.555	26	A	556	556	3 d	73.908	6	B	......	......

TABLE 2.—Standard Wave Lengths in the Iron Arc Spectrum—Continued.

Intensity, group, and class.	λ B. S.	Number of observations.	Probable error.	Secondary standards.	Interpolated.	Intensity, group, and class.	λ B. S.	Number of observations.	Probable error.	Secondary standards.	Interpolated.
4 a 3......	5497.520	22	A	522	522	5 b 4.....	6191.564	22	A	568	568
4 a 3......	5506.783	23	A	784	784	3 b 4.....	6219.287	11	A	....	290
5 d 5......	69.627	21	A	633	....	5 b 4.....	30.730	23	A	734	734
6 d 5......	5586.764	24	A	772	....	4 b 4.....	52.562	15	A	....	567
6 d 5......	5615.653	23	A	661	....	3 b 4.....	65.140	14	B	145	145
5 d 5......	24.551	15	B	....	....	3 b 4.....	6297.800	6	A	....	803
4 d 5......	58.827	20	A	836	....	5 d 5.....	6301.514	18	A	....	....
3 d........	5662.526	8	B	....	....	4 b 4.....	18.024	16	A	028	028
3..........	5701.554	10	A	....	....	4 b 4.....	35.338	18	A	341	342
3 d........	09.388	16	A	396	....	5 b 4.....	6393.607	22	A	612	612
3 d........	53.131	6	B	....	....	5 d 5.....	6400.014	4	B	....	....
4 d........	5763.002	15	B	013	....	5 d 5.....	11.662	4	C	....	....
4 e........	5862.354	5	B	....	....	4 b 4.....	21.355	17	A	....	362
6 e........	5914.172	3	A	....	....	5 b 4.....	30.853	22	A	859	859
4..........	5934.668	6	C	....	....	5 b 4.....	6494.987	24	A	993	993
4 e........	6024.066	14	A	....	....	5 b 4.....	6546.247	18	A	252	252
2 b 4......	27.058	6	A	059	059	5 b 4.....	6592.920	16	A	928	927
4 b 4......	6065.489	20	A	492	492	4 b.......	6663.447	6	B	....	455
4 b 4......	6136.623	6	C	....	624	5 b 4.....	6677.994	17	B	8.004	8.001
4 b 4......	37.697	21	A	701	702						

IV. DISCUSSION.

Table 2 shows, first of all, that the values for c and d lines as derived from the long arc are distinctly smaller than the adopted secondaries, thus confirming in a qualitative way the results of St. John and Babcock, who found that the lines of groups c and d were displaced with respect to the lines of groups a and b. For 23 lines belonging to groups c and d the secondary standards minus our new values averages +0.0072 A.

It is also evident that there is a systematic difference for the remaining lines, 44 of which have been recognized as belonging to groups a and b. The difference between the international values and our redeterminations averages +0.0029 A for these 44 lines. We have searched diligently for an explanation of this divergence, but are unable to account for it in an entirely satisfactory manner. It was suspected that at least a part of the difference might be ascribed to a change in wave length of a and b lines when these are derived from the long arc instead of from the short one, which served as a source for the internationally adopted measurements. An independent investigation on standards among the longer waves of iron was made recently with a 6-mm 6-ampere arc.[18] Omitting poor determinations, 34 lines with group designations are common to these two sets of measurements; these are given in Table 3 for purposes of comparison. Ten lines of group d average

[18] B. S., Sci. Papers, No. 479.

0.0047 A longer in the shorter arc, but the average value for 22 lines of groups a and b is only 0.0004 A greater in the shorter arc. In other words, the new measurements with the short arc deviate from the so-called stable international standards by nearly the same amounts as the redeterminations from the new arc, indicating that the modifications in the arc do not change these values more than a few ten-thousandths of an Angstrom.

TABLE 3.—New Values from Long and Short Arcs Compared with Secondaries.

Intensity, group, and class.	12-mm 5-ampere arc.	6-mm 6-ampere arc.	Secondaries.	Intensity, group, and class.	12-mm 5-ampere arc.	6-mm 6-ampere arc.	Secondaries.
6 a 4	5434.527	525	527	3 b 4	6219.287	286	....
6 a 4	55.613	614	614	5 b 4	30.730	730	734
4 a 3	5497.520	520	522	4 b 4	52.562	564	....
4 a 3	5506.783	782	784	3 b 4	65.140	140	145
5 d 5	67.627	631	633	3 b 4	6297.800	800	....
6 d 5	5586.764	770	772	5 b 5	6301.514	515	....
6 d 5	5615.653	658	661	4 b 4	18,024	025	028
5 d 5	24.551	555	....	4 b 4	35.338	338	341
4 d 5	58.827	834	836	5 b 4	6393.607	608	612
3 d	5662.526	529	....	5 d 5	6400.014	018	....
3 d	5709.388	392	396	4 b 4	21.355	356	....
3 d	53.131	138	....	5 b 4	30.853	853	859
4 d	5763.002	009	013	5 b 4	6494.987	988	993
4 e	6024.066	060	....	5 b 4	6546.247	247	252
4 b 4	6065.489	489	492	5 b 4	6592.920	922	928
2 b 4	37.697	699	701	4 b	6663.447	447	....
5 b 4	6191.564	565	568	5 b 4	6677.994	994	8.004

Considering the circumstances under which the original observations were made, we have been forced to the conclusion that the adopted system of international secondary and tertiary standards may be slightly in error. As stated before, the wave-length comparisons upon which the international standards are based were made before the effects of certain variations in operating conditions of the sources were appreciated or quantitatively determined. The so-called pole effect in the iron arc is an example of the resulting uncertainty in a wave length when the source is not accurately described. Similar uncertainty may exist for the cadmium standard when the original source which defined the unit of wave length (International Angstrom unit) is not adhered to. In all of our work on secondary standards we have used, as the primary standard, the low vapor-pressure cadmium tube, whose red radiation was measured relative to the meter, and our experience with this source indicates that the wave length of the red line is constant and reproducible well within the limiting precision attainable in wave-length comparisons.[19]

[19] B. S., Sci. Papers, 18, p. 188; 1922.

It is to be regretted that other laboratories have not made more use of this source, and it is, perhaps, a serious matter that none of the measurements on which the international system was based were made directly from the primary standard as defined. Fabry and Buisson [20] in measuring 115 iron lines (2374 to 6495 A) referred these to an auxiliary standard (5460.741 A) from the mercury spectrum as emitted by a Cooper-Hewitt lamp. This line is known to have a very complex fine structure and its effective wave length in interferometers is, therefore, highly irregular.[21] Eversheim [22] employed the Heraeus arc lamp, which contained a cadmium amalgam and was operated with 4.5 amperes on a 220-volt circuit. Furthermore, the complex blue line (5085.822 A) was often used instead of the red line (6438.4696 A). A similar cadmium arc and procedure was employed by Pfund.[23]

Discrepancies and systematic differences, exceeding the probable errors, exist among these first determinations.[24] For example, the standard 6678.004 A is based upon the observations 8.000, 8.004, and 8.008 A, while our value from either the short or the long arc is 6677.994 A.

It may, therefore, be questioned if the adopted system of secondary standards is in a sufficiently satisfactory condition, since it is not based on the strictly defined primary standard, and the values were obtained before detailed specifications for the iron arc existed. The accuracy of both absolute and relative values might be increased by remeasurement with the long arc which gives somewhat sharper lines. In our opinion, it is highly desirable to have a system of international standards of wave length determined as accurately as possible, and strictly according to the logical definitions of such a system.

WASHINGTON, August 20, 1923.

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[20] Astroph. Jour., **28**, p. 169; 1908.

[21] Perard, Comptes Rendus., **176**, p. 1060; 1923.

[22] Ann. der Phys., **30**, p. 815; 1909.

[23] Astroph. J., **28**, p. 197; 1908.

[24] Phys. Rev., **31**, p. 602; 1910.

INDEX TO VOLUME 19

A

B

C

D

L

M

N

O

P

R

S

Morrill